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High-resolution group III nitride microdisplays

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Full-scale self-emissive displays based on gallium nitride micro-size LEDs may be suitable for ultra-portable products such as next-generation handheld projectors.

Microdisplays, which find use in head-wearing displays, camcorders, and viewfinders, are small high-resolution displays that are typically magnified by optics to enlarge the image that the user views. They are currently based on technologies such as liquid-crystal displays, organic LEDs (OLEDs), digital light processing, and laser beam steering. They can also be fabricated using micro-LED (μLED) arrays made with group III nitride (III-nitride) semiconductors. Such devices would benefit from the outstanding physical properties of III-nitrides such as gallium nitride (GaN) and indium gallium nitride (InGaN), the tunable emission wavelength of InGaN, and the ability of the μLEDs to be integrated with other functional devices. III-Nitride microdisplays could play an important role in ultra-portable products such as next-generation handheld projectors, wearable and head-up displays, as well as in emerging fields such as biophotonics and optogenetics.

For many years, GaN monolithic μLED arrays have remained operational only in the passive mode, where one row at a time can be independently accessed. This requires a high source voltage because an entire pixel column is driven in series, while the appropriate LED is turned on or off using row addressing. This has, in turn, limited the arrays to a small number of pixels.

We have realized full-scale (640×480 Video Graphics Array) high-resolution self-emissive microdisplays based on GaN μLEDs and operating in an active driving scheme.[1] These devices have evolved from technology invented and patented 10 years ago.[2–4] An active matrix display means that each pixel is geared with its own driver circuit that is capable of storing data and driving each individual μLED. In addition to being energy-efficient, our devices have high brightness, high contrast, and high-resolution green (517nm) and blue (462nm) pixels.

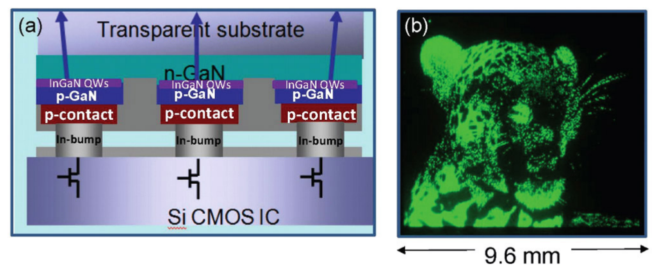

Figure 1. *(a) Flip-chip bonding between a micro-size LED (μLED) matrix array and the silicon CMOS driver integrated circuit via indium bumps forms an integrated microdisplay in one package. (b) Grayscale projected image of a leopard from a green video graphics array indium gallium nitride (InGaN) microdisplay (640×480 pixels, each 12μm in size with 15μm between them) operating at a driving current of 1μA per pixel. QW: Quantum wells. n-GaN: n-Type gallium nitride. p-GaN: p-Type gallium nitride. Si: Silicon.*

Several advances were key to this development. One was achieving a low contact resistance of μLEDs with 12μm pixel size. Another was the design and fabrication of an active matrix driver integrated circuit. Finally, it required hybrid integration of the InGaN μLED array with the silicon integrated circuit chip using flip-chip bonding, which involves interconnecting semiconductor devices together through tiny solder bumps.

The fabrication steps of μLED arrays (with 12μm pixel size and 15μm pitch, or distance between pixels) consisted of standard GaN processes of photolithography, etching, and metallization. In an active matrix display, the pixels share a common anode (made of an n-type material that has an abundance of electrons) with an independently controllable cathode (made of a p-type material with an abundance of positive-charge-carrying 'holes').

For improved performance, we adopted a heavily magnesium-doped p-type GaN layer as the cathode contact layer to minimize the contact resistance. We implemented a digital CMOS process to design and fabricate active matrix 640×480 and 160×120

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microdisplay controller integrated circuits. These circuits have a μLED current of 0.5–10μA and the same pitch of 15μm as the μLED array. Figure 1(a) shows the interconnection between the array and the silicon CMOS driver integrated circuit accomplished by flip-chip bonding using indium bumps 6μm in size, which were deposited by thermal evaporation. The hybrid integration means that thousands of signal connections between the microdisplay and the driving circuit have been established in a single flip-chip bonding package.

The measured luminance level of the microdisplays is much higher than that of LCD and OLED devices. Figure 1(b) shows a grayscale projected image of a leopard from a green InGaN microdisplay with 640×480 pixels. The device is fully compatible with current video graphics technology. The pixel emission intensity was almost constant over an operational temperature range from 100 to -100°C. The outstanding performance is a direct attribute of III-nitride semiconductors. We intend to optimize the prototype device for commercialization.

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